Overview of BTeV Physics, the Components and the Requirements

The Physics: General

Mysteries

Solutions:
New Physics

Dark Matter

new particles

LHC
New Particles

new physics, found 1st in either place; specified in both

Dominance of Matter over Antimatter

new source of CP violation

$\cancel{CP}$ & Rare b & c decays
BTeV

ν Mixing

new models of GUTS & flavor

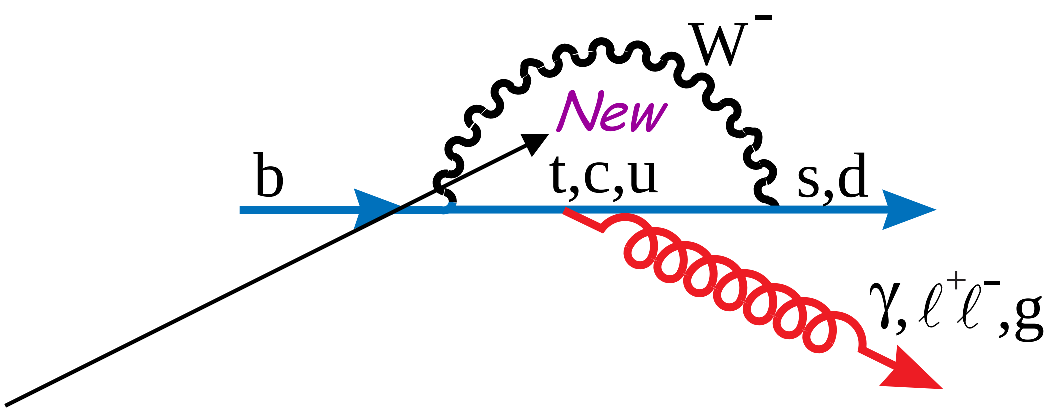
Dark Energy

? new forces, dimensions?

Hubble
JDEM

The Physics: More Specific

- CP Violation: Particles behave differently than antiparticles
  - Demonstrated in B decays by BaBar & Belle (one ∠ measured, β)
  - But there are 4 different angles to determine
  - New Physics can show up as inconsistencies between/among CP measurements and other quantities
- Rare Decays

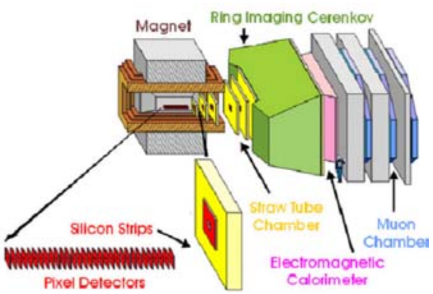


  - New Particles can appear in the loop & interfere

Project Scope

WBS 1.0

BTeV Detector



WBS 4.0

BTeV Project

WBS 3.0

WBS 2.0

Requirements on C0 IR

- Peak Luminosity ~2×10^{32} cm^{-2} s^{-1} (β^*<50 cm)
- Interoperability: Must allow for operation at C0 or at B0 & D0 simultaneously
- Non-interference with BTeV detector – last quadrupole closest to collision point is 5 m further away than in CDF or D0
- Schedule: Must be ready by shutdown in middle of 2009

Requirements on C0 Outfitting *(WBS 3.0)*

- Building already exists
- We need to
  - Provide the architectural, structural, mechanical and electrical work for the BTeV detector (WBS 1.0).
  - Provide the modifications to the C-0 Service Building and primary power for the Interaction Region (WBS 2.0).

BTeV Collaboration

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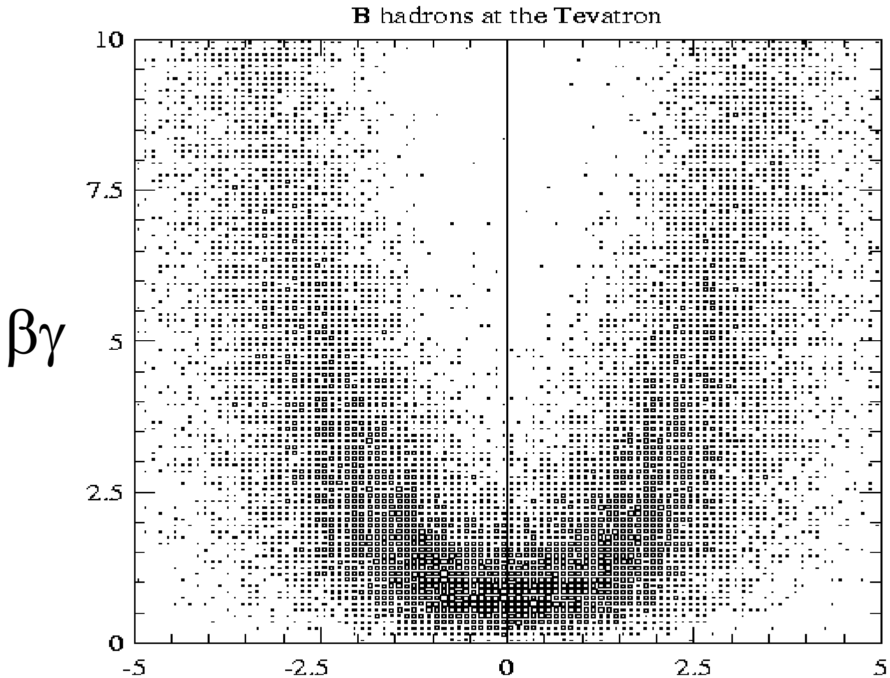
Characteristics of hadronic b production

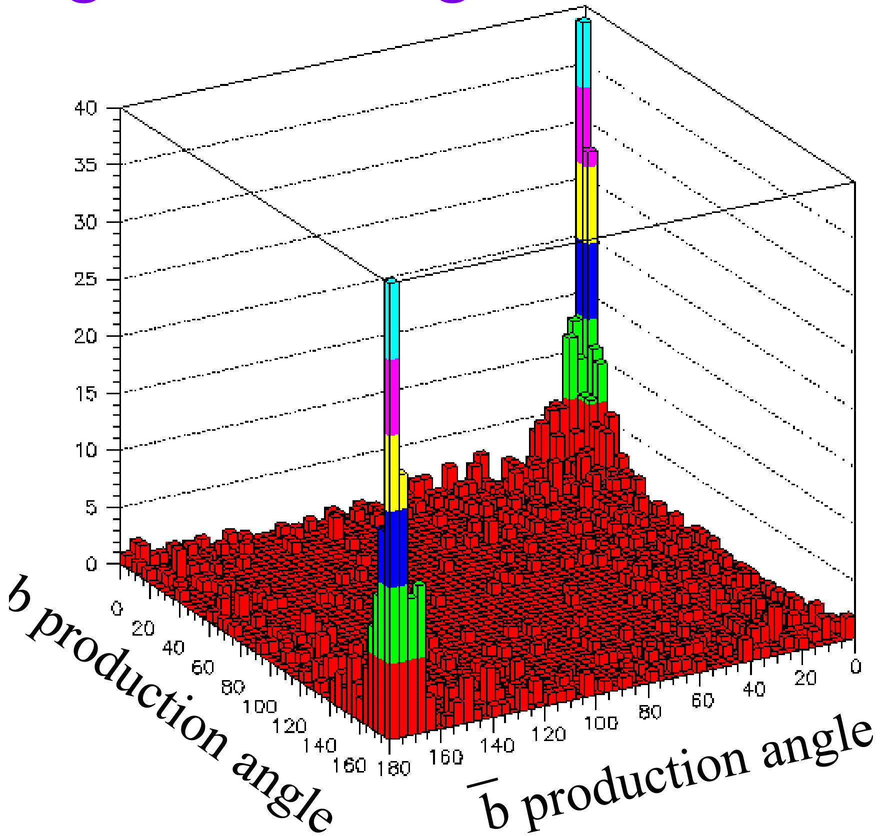
$$p\bar{p} \rightarrow b\bar{b} + X$$

The higher momentum b's are at larger η's

b production peaks at large angles with large $\bar{b}b$ correlation



$$\eta = -\ln(\tan\frac{\theta}{2})$$



BTeV Co

Requirements: General

- Intimately tied to Physics Goals
- In general, within the acceptance of the spectrometer (10 – 300 mr with respect to beam) we need to:
  - Detect charged tracks & measure their 3-momenta
  - Measure the point of origin of the charged tracks (vertices)
  - Detect neutrals & measure their 3-momenta
  - Reveal the identity of charged tracks (e, μ, π, K, p)
  - Trigger & acquire the data (DAQ)
- Detector we designed meets the requirements

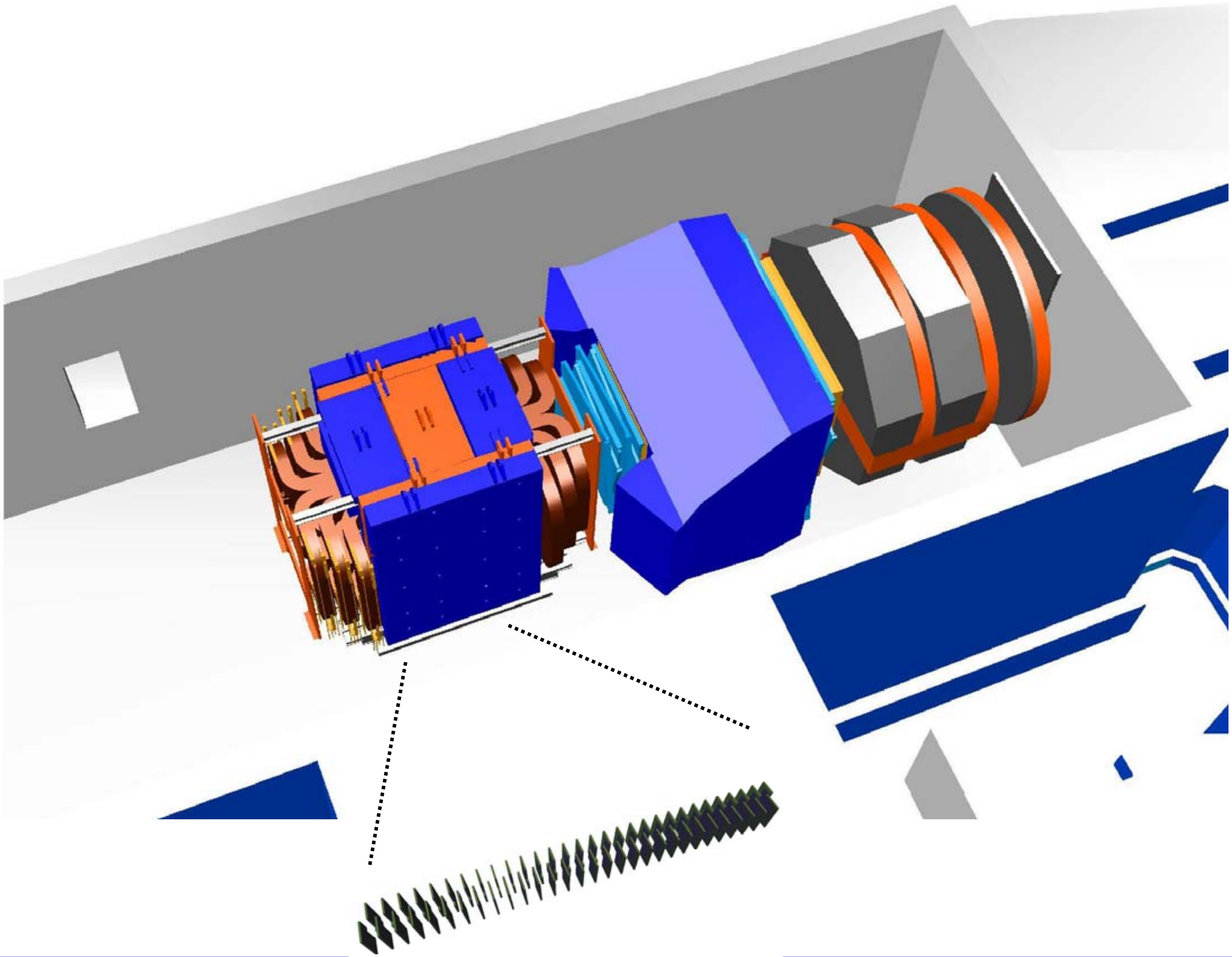
Basics Reasons for the Requirements

- B's (& D's) are long lived, ~1.5 ps, so if they are moving with reasonable velocity they go ~3 mm before they decay. This allows us to Trigger on the the presence of a B decay (*detached vertex*).
- B's are produced in pairs $p\bar{p} \rightarrow b\bar{b}+X$, and for many crucial measurements we must detect one b fully and some parts of the other: "flavor tagging"
- Physics states of great interest now are varied and contain both charged modes and neutrals, B_d & B_s

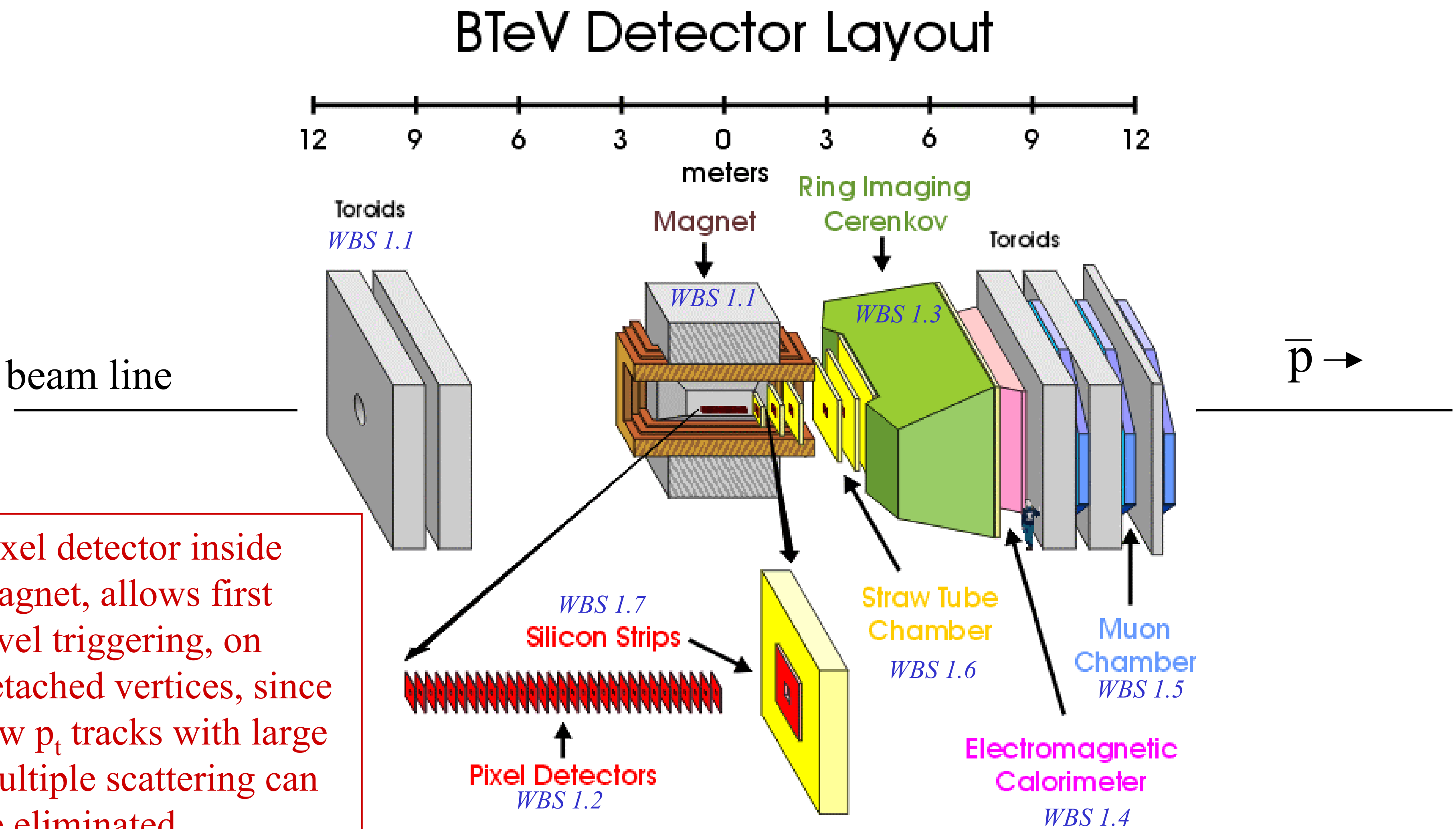
More Basic Reasons

- Many modes contain γ, π^o & η, so need excellent electromagnetic calorimetery
- B_s oscillations are fast, so need excellent time resolution ~<50 fs, compared to ~1500 fs lifetime. Also very useful to reduce backgrounds in reconstructed states
- Physics Backgrounds from $\pi \Leftrightarrow K$ can be lethal
  - $B_s \to D_s\, \pi^-$ is 15X $B_s \to D_s\, K^-$
  - $B^o \to K^* \pi \to K^\mp \pi^\pm \pi^o$ is 2X $B^o \to \rho\pi \to \pi^+\pi^-\pi^o$
  - So excellent charged hadron identification is a must

The BTeV detector in the C0 collision hall



The BTeV Detector

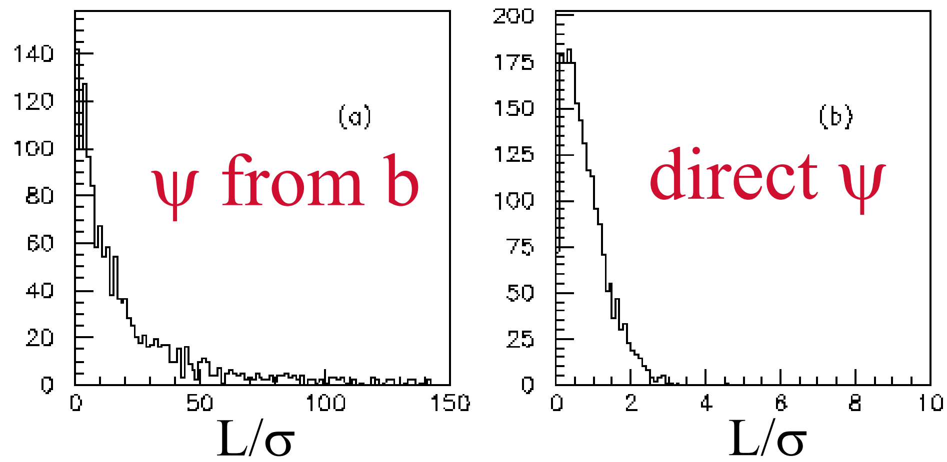


Pixel detector inside magnet, allows first level triggering, on detached vertices, since low p_t tracks with large multiple scattering can be eliminated

Fundamentals: Decay Time Resolution

- Excellent decay time resolution
  - ➢ Reduces background
  - ➢ Allows detached vertex trigger
- The average decay distance and the uncertainty in the average decay distance are functions of B momentum:

$$\langle L \rangle = \gamma\beta c\tau_B$$
$$= 480\ \mu m \times p_B/m_B$$

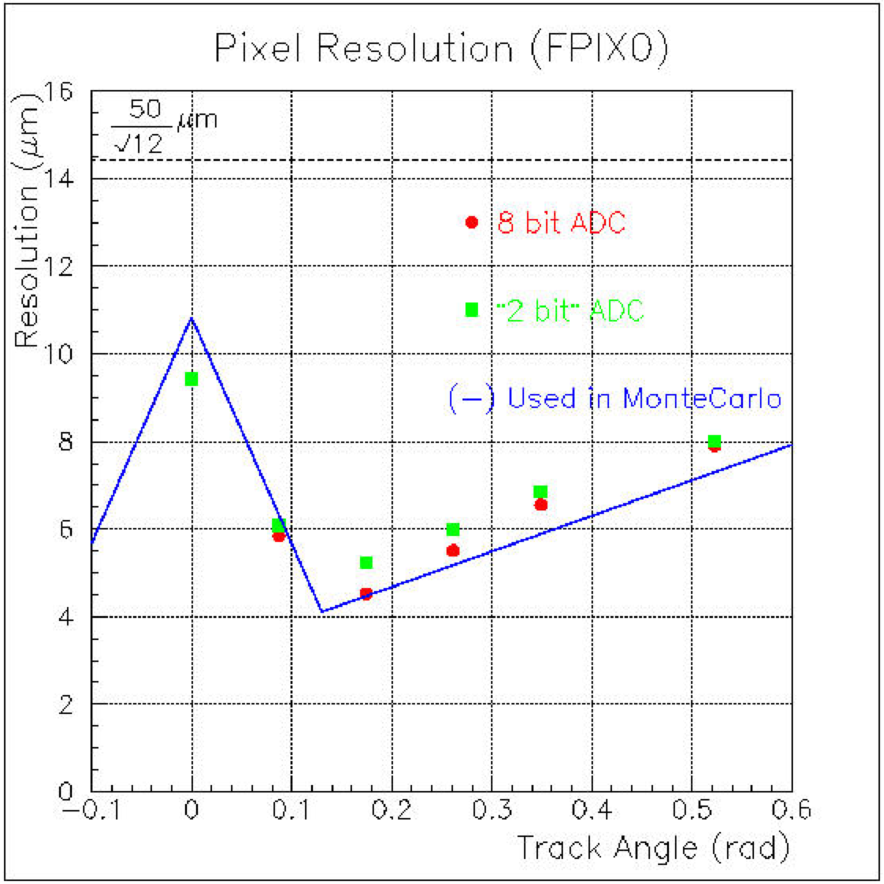


CDF/D0 region

LHC-b region

Pixels *(WBS 1.2)*

- Pixel – working systems studied in beams, including "almost" final electronics
- Full mechanical design done and being tested
- Pixels are inside of beam pipe in machine vaccum – OK with accelerator provided the outgassing rate is below specified limits (review document linked to Review web page)



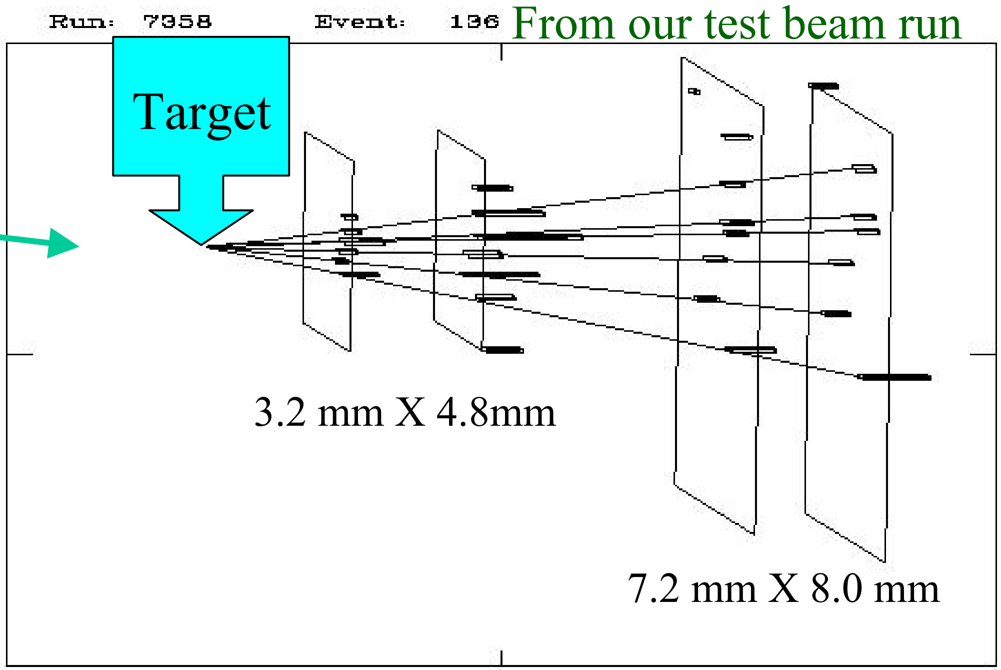
Physics Simulations Tools

- Full GEANT has multiple scattering, bremsstrahlung, pair conversions, hadronic interactions and decays in flight; smears hits and refits the tracks using "Kalman Filter." No pattern recognition (except for trigger). However, we do not expect large pattern recognition problems

- **This track density is 3x higher than what is expected in BTeV!**

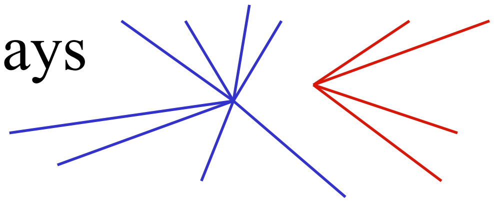
◆ Detailed studies of efficiency and rejection for up to an average of six interactions/crossing

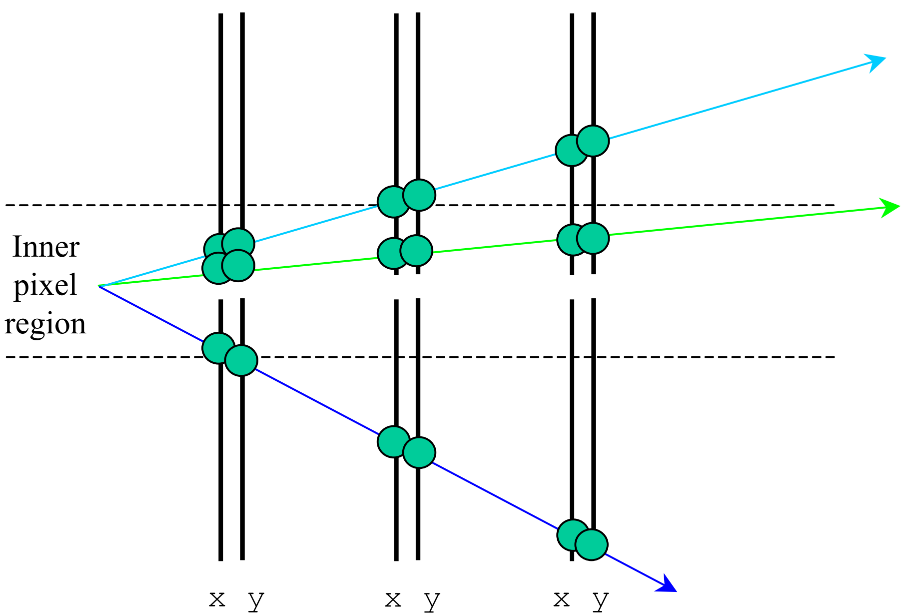
From our test beam run



Pixel Trigger Overview *(WBS 1.8)*

◆ Idea: find primary vertices & detached tracks from b or c decays





- Pixel hits from 3 stations are sent to an FPGA tracker that matches "interior" and "exterior track hits
- Interior and exterior triplets are sent to a farm of DSPs to complete the pattern recognition:
  - interior/exterior triplet matcher
  - fake-track removal

Trigger Performance

- For a requirement of at least 2 tracks detached by more than 4σ, we trigger on only 1% of the beam crossings and achieve the following efficiencies for these states at Level I:

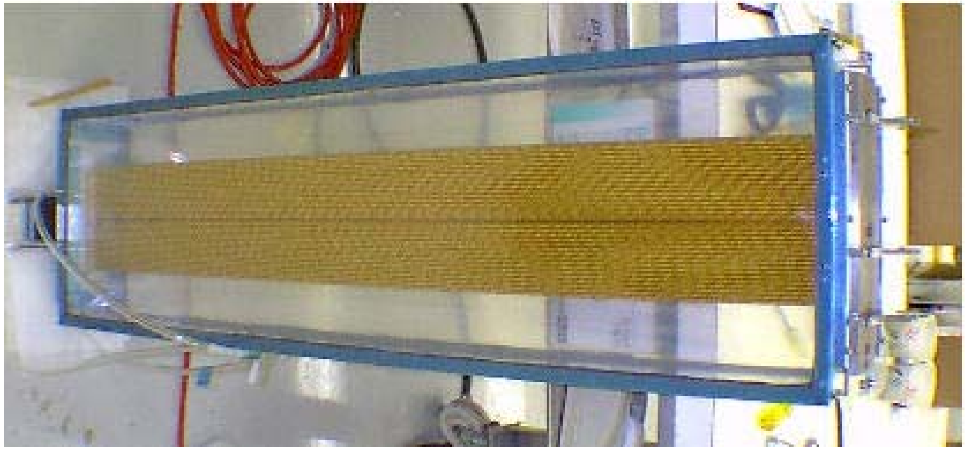
State	efficiency(%)	state	efficiency(%)
$B \rightarrow \pi^+\pi^-$	55	$B^o \rightarrow K^+\pi^-$	54
$B_s \rightarrow D_s K$	70	$B^o \rightarrow J/\psi\ K_s$	50
$B^- \rightarrow D^o K^-$	60	$B_s \rightarrow J/\psi K^*$	69
$B^- \rightarrow K_s \pi^-$	40	$B^o \rightarrow K^* \gamma$	40

@ 2 int/crossing

Tracking

- Straws *(WBS 1.6):*

  protoype undergoing tests, uses Atlas design as basis

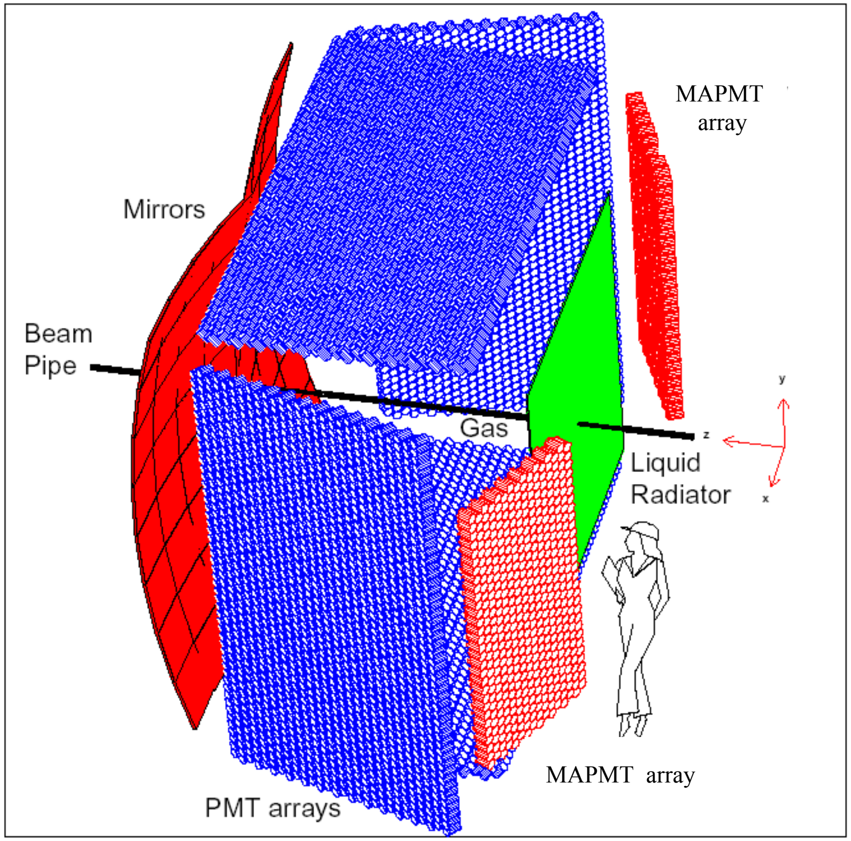


- Silicon Strips

  (WBS 1.7): simple single sided design, mechanics done.

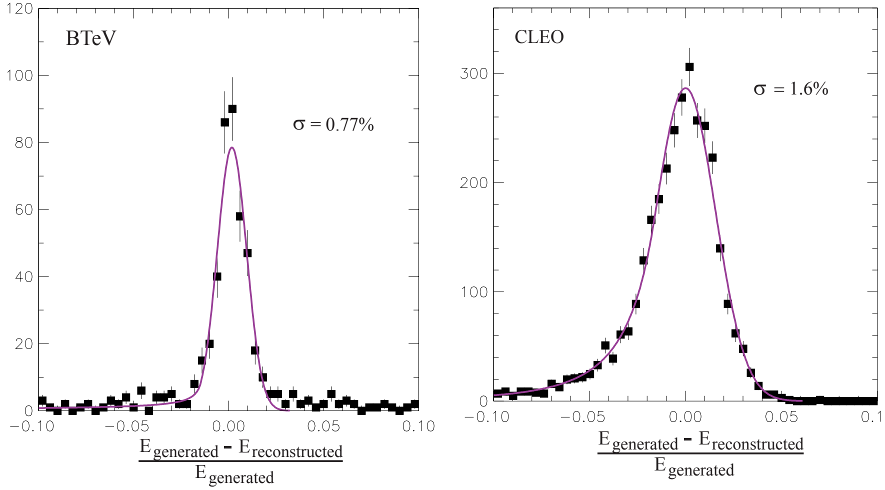
RICH *(WBS 1.3)* : Two Systems

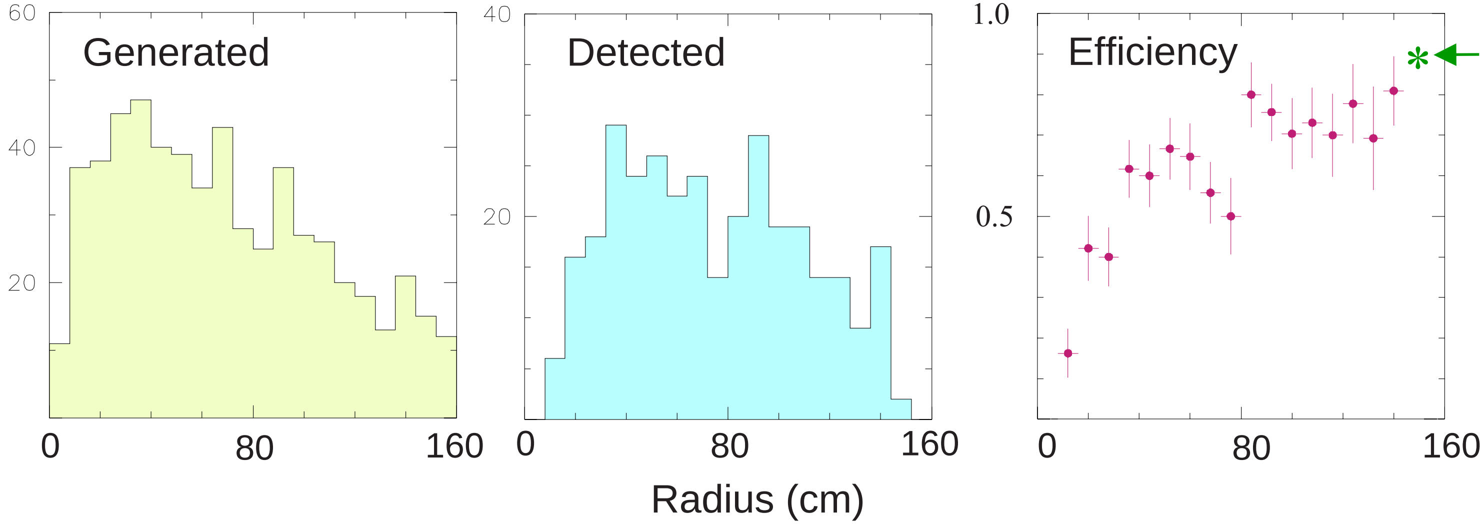
- Gas + Mirror + MAPMT to identify b decay products
- Liquid + PMT's to help with flavor tagging of b's (p/K separation for p < 9 GeV/c)
- Excellent particle id. distinguishes BTeV from "Central pp Detectors"



EM cal *(WBS 1.4)* using $PbWO_4$ Crystals

- GEANT simulation of $B^o \rightarrow K^*\gamma$, for BTeV & CLEO
- Isolation & shower shape cuts on both





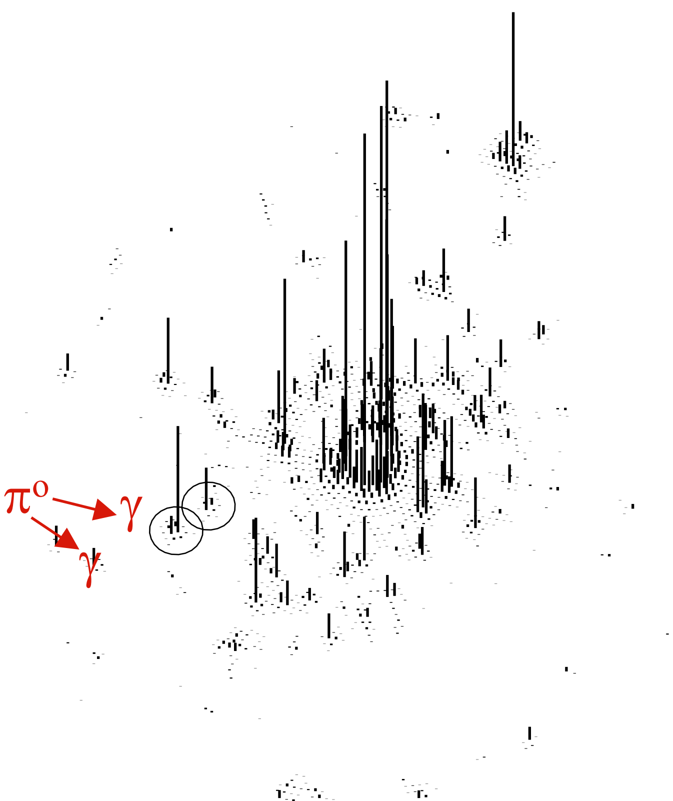
CLEO barrel ε=89%

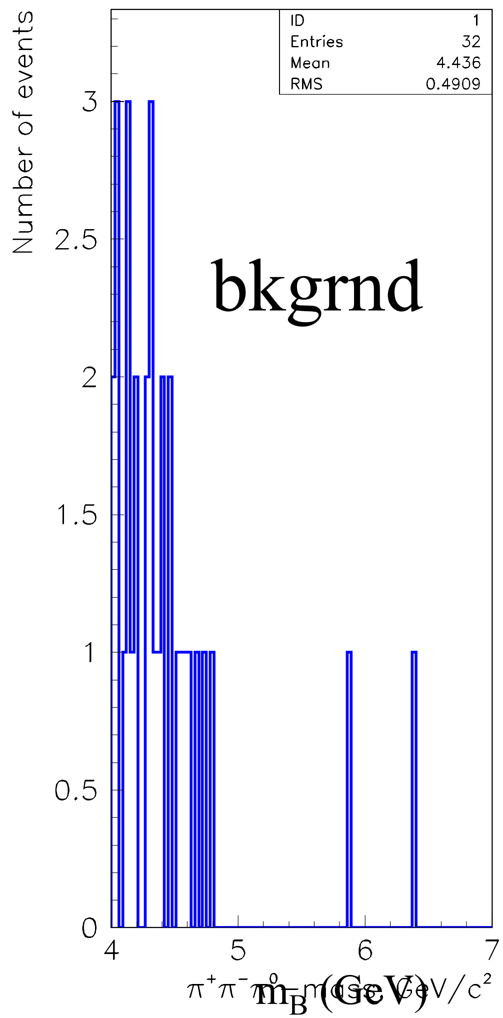
$B^o \rightarrow \rho\pi$

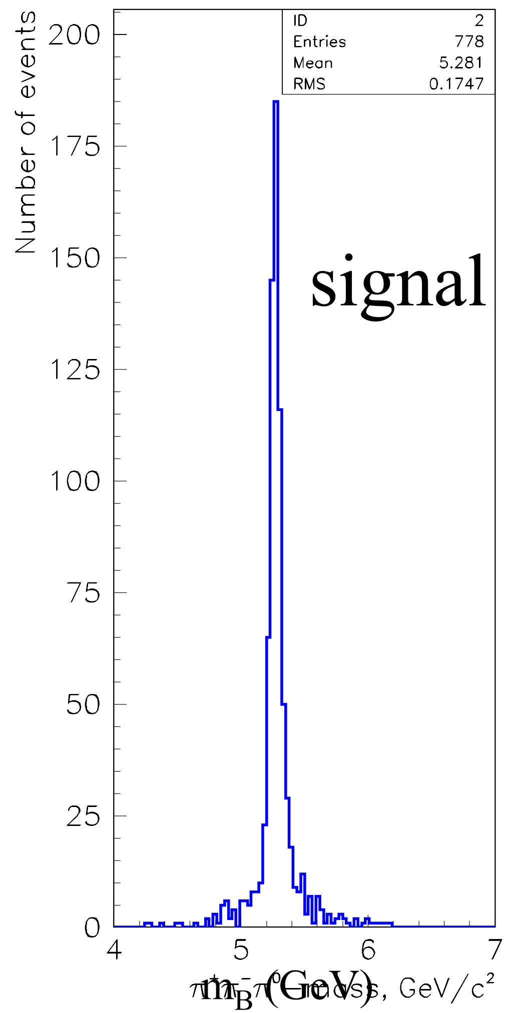
Based 9.9×10^6 bkgrnd events

$B^o \rightarrow \rho^+\pi^-$ S/B = 4.1

$B^o \rightarrow \rho^o\pi^o$ S/B = 0.3







Muon System *(WBS 1.5)*

- Used to check detached vertex trigger by having an independent di-muon trigger
- Also used for μ id
- Tested in beams
- Robust design: stainless steel tubes

Kinds of Requirements

- One set of requirements is based on the physics performance we want the detector to provide
- A second set is internal to the detector subsystem of interest and tells how each individual piece needs to perform (i. e. the efficiencies of PM tubes, or noise on electronics)
- I will concentrate on the first set here

Fundamentals

- Luminosity up to 2×10^{32} $cm^{-2}s^{-1}$
- Mean number of interactions per crossing of 6 (thus allowing for 396 ns bunch spacing)
- Time between bunches < 100 ns (thus allowing for 132 ns bunch spacing)
- Radiation Resistance for at least 10 years on all detector components

High Level Requirements

- Charged Tracks
  - Angular acceptance: 10 - 300 mr
  - p > 3 GeV/c
  - Tracking efficiency > 98%
  - Mass resolution < 50 MeV/c
  - Primary vertex resolution (along beam) < 100 μm
- Trigger efficiency & rejection
  - ε > 50 % for all B decays with ≥2 charged tracks
  - ε > 20 % for all B decays with 1 charged track
  - Trigger rejection > 98% on light quark events (Level I), and 99.9% at Level III with only a 10% further loss in b efficiency
  - Maximum data rate to archival storage < 200 Mbyte/sec

Hadron & Lepton Identification

- π/K separation $\geq 4\sigma$ for momenta 3 - 70 GeV/c
- p/K separation $\geq 3\sigma$ for momenta 3 - 70 GeV/c
  - These allow for π/e & π/μ separation at 4σ level up to ~23 and ~17 GeV/c, respectively
- positive μ identification from 5 - 100 GeV/c with a fake rate < 10^{-3} and an independent momentum determination with resolution

$$\frac{\sigma_p}{p} = 19\% \oplus 0.6\% \times p$$

Electromagnetic Calorimeter *(WBS 1.4)*

- Radius up to 160 cm ~220 mr, with hole for beam ~10 mr
- Range E > 1 GeV
- Energy resolution

$$\frac{\sigma_E}{E} < \frac{2\%}{\sqrt{E}} \oplus 1\%$$

- Position resolution

$$\sigma_x < \frac{4\ \mathrm{mm}}{\sqrt{E}} \oplus 1\mathrm{mm}$$

BTeV/Co

Physics Reach (CKM) in 10^7 s

Reaction	$\mathcal{B}$(B)($\times10^{-6}$)	# of Events	S/B	Parameter	Error or (Value)
$B^o \to \pi^+\pi^-$	4.5	14,600	3	Asymmetry	0.030
$B_s \to D_s K^-$	300	7500	7	γ	8^o
$B^o \to J/\psi K_S$ $J/\psi \to l^+l^-$	445	168,000	10	sin(2β)	0.017
$B_s \to D_s \pi^-$	3000	59,000	3	x_s	(75)
$B^- \to D^o (K^+\pi^-) K^-$ $B^- \to D^o (K^+K^-) K^-$	0.17 1.1	170 1,000	1 >10	γ	13^o
$B^- \to K_S \pi^-$ $B^o \to K^+\pi^-$	12.1 18.8	4,600 62,100	1 20	γ	$< 4^o$ + theory errors
$B^o \to \rho^+\pi^-$ $B^o \to \rho^o\pi^o$	28 5	5,400 780	4.1 0.3	α	$\sim 4^o$
$B_s \to J/\psi\, \eta$, $B_s \to J/\psi\, \eta'$ $J/\psi \to l^+l^-$	330 670	2,800 9,800	15 30	sin(2χ)	0.024

@2 int/xing

Endorsements & Schedule

- BTeV was included as a near term priority in the category of "Highest Scientific Importance and Near-term Readiness for Construction," in the "Facilities for the Future of Science: A Twenty-year Outlook" report of the Office of Science.
- Based on our physics sensitivities, and **implementation in 2009** a HEPAP subpanel wrote: "**P5** supports the construction of BTeV as an important project in the world-wide quark flavor physics area. Subject to constraints within the HEP budget, **we strongly recommend an earlier BTeV construction profile** and enhanced C0 optics"
- *Presidents FY2005 Budget Request: "The BTeV experiment will have scientific competition from a dedicated B physics experiment at the CERN LHC, so timely completion of BTeV is important."*